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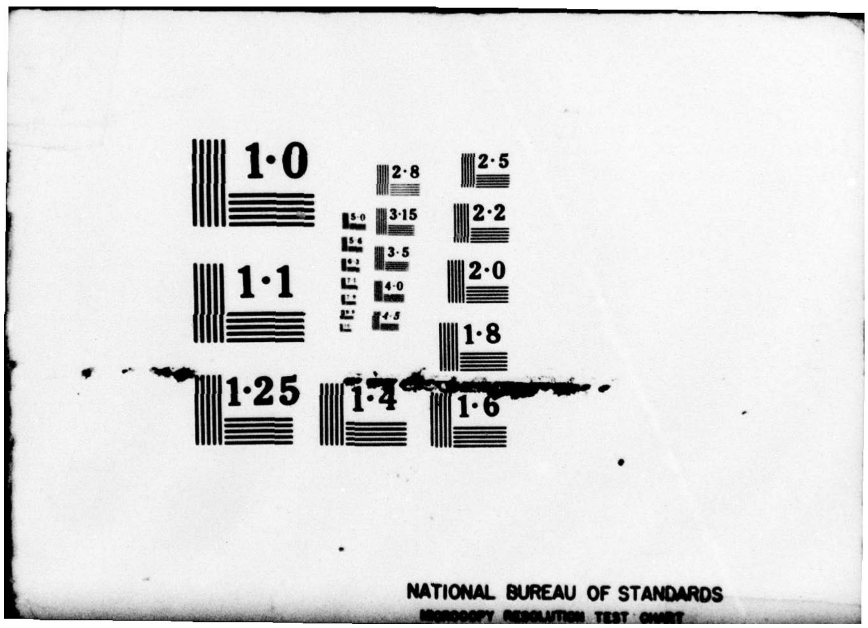
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Heterojunctions between amorphous semiconductors and crystalline semiconductors have been investigated in detail. In particular, chalcogenide-glass /n-Si, chalcogenide-glass/p-Si, chalcogenide-glass/a-Si, and chalcogenide glass/n-GaAs heterojunctions were fabricated and analyzed. Band models which explain the electronic and optical behavior have been derived. It was shown that these band models remain valid when the chalcogenide glasses are switched into the on state. A transistor was fabricated in which the glass served as contd. → next page

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the emitter. The current gain increases by a factor of about 1000 when the glass is switched. These results together with pulse studies resulted in a complete analysis of the threshold switching and recovery processes.

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1.0 Amorphous-Semiconductor Heterojunctions

1.1 Band Models for Chalcogenide-Glass/Crystalline-Silicon Heterojunctions

Band models previously applied to off-state chalcogenide-glass/crystalline-Si heterojunctions have been generalized considerably. In particular, they have been extended to account for large variations in doping concentration in the silicon and have been shown to be applicable after the threshold-type glass-s have been switched into the on state. In addition, transient-on-characteristics and recovery curves have been measured and shown to be consistent with the band models. An important new consequence of the heterojunction results is that the on-state can be sustained by the injection of electrons from the glass into the silicon. This is contrary to several double-injection models for switching.

1.2 Electronic Properties of Chalcogenide-Glass/Crystalline-Silicon Heterojunctions

Low-field studies of crystalline/amorphous heterojunctions have shown that the space-charge region in the glass is more extensive (1000-2000 Å from the interface) than previously believed. In addition, the density of interface states turns out to be much smaller (3×10^{12} cm^{-3}) than in crystalline heterojunction systems. This could arise from the lack of a fixed lattice in amorphous systems, and suggests a great advantage of glass/crystalline heterojunctions in device design. The resulting electronic behavior is that of an ideal heterojunction.

1.3 Properties of Chalcogenide-Glass/Amorphous-Silicon Heterojunctions

Thin-film chalcogenide-glass/amorphous Si heterojunction devices were fabricated by rf sputtering and photolithographic techniques. Conductivity as a function of voltage and temperature, photoresponse, and switching were

observed in an attempt to characterize the heterojunction band structure and switching properties. Conductivity was found to be completely symmetric with respect to applied-voltage polarity, and to exhibit normal semiconducting temperature behavior: $\sigma = \sigma_0 \exp(-E_a/kT)$. The heterojunction capacitance was independent of the magnitude and polarity of the bias voltage, indicating that any space-charge regions are narrow. The photoresponse results indicated a barrier height of 0.67 eV at the interface between the glass and Mo electrode, but no signal attributable to the heterojunction was observed, suggesting that the bands are flat near that interface.

In addition to the normal switching observed in single component devices, a unique secondary switching phenomenon was found to occur after application of moderately high current levels. This took the form of switching from the normal on state to either a single, stable, high-conductivity state or multiple, unstable, high-conductivity states. After prolonged secondary switching, the normal on state disappeared entirely, leaving only the off state and the high-conductivity states. The secondary switching could be associated with effects in the amorphous Si, most likely a partial crystallization due to excessive heating. Switching is symmetric with respect to voltage polarity, except for a slight increase in delay time and decrease in holding voltage when the chalcogenide side of the heterojunction is negatively biased.

1.4 Properties of Chalcogenide-Glass/GaAs Heterojunctions

The on-state current-voltage characteristics of chalcogenide-glass/n-GaAs heterojunctions have been measured. The results have been analyzed using previously determined boundary conditions for GaAs devices and the on-state characteristics of the glass. The results show that a large electric

field is present at the glass/GaAs interface when electrons are injected into the GaAs, implying that a negative charge density exists in the glass near the interface. A band model has been developed to explain these results.

2.0 Amorphous/Crystalline Heterojunction Transistors

A unique device employing a threshold-type chalcogenide glass as one terminal and crystalline Si or Ge as the other two terminals of a heterojunction transistor has been fabricated. The device exhibits strikingly different behavior depending on whether the glass is in the off state or the on state. In the off state, no gain has been observed. However, once the glass is switched, either current gain or voltage gain is possible, depending on the configuration. Current gains in excess of 10 have been observed. The device can be operated so that it will remain in the high-gain state after the switching pulse is entirely removed. Short-pulse experiments indicate that operation is electronic rather than thermal. Previous results on amorphous-crystalline heterojunctions have been used to construct a band model for the transistor. This model was also used to analyze the steady-state and pulsed-mode characteristics of the device. New studies of the on-state current density and carrier concentration were used to calculate the expected gain as a function of current and base doping concentration, with results in good agreement with the experimental data. The behavior of the devices provides another confirmation of the electronic nature of threshold switching in chalcogenide glasses. An additional implication of the data is the predominance of electrons rather than holes in the on state of the glass, in direct contrast to the low-field behavior.

3.0 <u>Studies of Chalcogenide-Glass Threshold Switching</u>

3.1 Size of the Conducting Filament in Threshold Switches

Four distinct sets of experiments have been carried out to determine the size of the conducting filament in the on state of an amorphous threshold switch as a function of steady-state current. It was found that the filament is much wider (e.g. 20 μm in diameter at 50 mA current) than is compatible with thermal calculations. An upper limit of 60°C can be established for the maximum temperature rise in the material for on-state currents between 10 mA and 200 mA. This establishes unambiguously the electronic nature of the on state.

3.2 Nature of the On State

A detailed study of the on state of amorphous threshold switches has been performed. Transient and steady-state I-V characteristics have been investigated as functions of film thickness, pore size, and electrode material. Velocity saturation effects in amorphous/crystalline Si heterojunctions and threshold recovery curves were also studied. It is found that the on-state resistivity is approximately 0.08 Ω cm, independent of electrode material. The on state is that of a semiconductor whose electronic band structure and carrier mobility are essentially unchanged from the off state, but in which a concentration of about 7×10^{18} free electron/cm^3 produces the high conductivity observed. The decay of the on state is due to a combination of the size of the conducting filament as a function of operating current. As expected, the current density in the filament is essentially independent of on-state current, provided the filament does not saturate the device pore. However, the filament turns out to be much larger than previous speculations, leading to the result that heating effects are negligible at currents below those for which the pore saturates.

3.3 Mechanism for Threshold Switching

Steady-state and time-dependent electrothermal calculations of the current-voltage characteristics and voltage-time profiles for chalcogenide-glass films have been calculated and the results compared with experiment. Agreement with experiment requires a critical electric field at which the switching transition begins. For switching without memory, it was found that (1) heating is insignificant and (2) the switching delay time cannot be a thermal effect. Consequently, a purely electronic model based on the unique electronic structure of chalcogenide glasses has been developed. The equal densities of positively and negatively charged traps that exist in the bulk are neutralized by the excess carriers that are produced by field-induced avalanche multiplication. This process of trap filling causes the delay time. When all the charged traps are neutralized, the drift mobility of a transition carrier increases by several orders of magnitude, thus producing the on state.

3.4 Recovery of the Off State

A model for the recovery of the off state after the holding voltage is removed from a chalcogenide-glass threshold switch has been developed. In this approach, the Schottky barrier near the cathode remains for a time, allowing carrier generation to proceed even in the absence of any applied field. This persistence of the cathode Schottky barrier is consistent with the valence-alternation model of Kastner, Adler, and Fritzsche, and is responsible for the detailed nature of the recovery curves. The conducting state then remains until radial ambipolar diffusion causes the filament to shrink to zero radius. Only after that point does generation cease. The model has been used to predict quantitatively the resistance of the device as a function of time for several different values of the operating cur-

rent. The results are in very good agreement with subsequently performed experiments.

4.0 Electron- and Photon-Induced Conductivity in Chalcogenide Glasses

A comprehensive study of the effects of electron and photon beams on the electrical properties of rf-sputtered chalcogenide-glass films of composition $Te_{40}As_{35}Si_{15}Ge_7P_3$ has been carried out. Optical results indicate that the material has a gap near 1.1 eV. Four major conclusions follow from a detailed investigation of the field and polarity dependence of the photocurrent: (1) the exponential increase of dark conductivity with electric field intensity is a carrier concentration rather than a mobility effect; (2) internal fields exists at molybdenum-chalcogenide junctions; (3) hole conduction dominates electron conduction at room temperature; (4) the chalcogenide bands bend up at the interface with molybdenum electrodes. Electron-beam-induced conductivity (EBIC) resulting from bombardment by 5-20 keV electrons has also been studied as a function of applied voltage on these films. A threshold energy of about 7 keV is necessary to obtain an EBIC signal, resulting from a schubweg of the order of 1000 Å and a film thickness of 1 μm. The photoconductivity and EBIC results are consistent and indicate that the product of mobility and lifetime for the carriers in these materials is approximately $2x10^{-10}$ cm^2/V. This corresponds to carrier lifetimes of the order of $2x10^{-11}$ sec. The drift mobility is trap controlled and of the order of $2x10^{-5}$ $cm^2/Vsec$.

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